United States Department of Agriculture
Soil Conservation Service
Albuquerque, New Mexico
Region 6

SELENIUM POISONING

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Regional Bulletin No. 99
Soil Series No. 7
April 1945

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INTRODUCTION

Alkali disease was described accurately in 1860 at an army post in South Dakota (22) but it has been only in the last 15 years that selenium poisoning was shown to be the cause of alkali disease. Although Moxon and Rhian (22) list 195 references pertaining to selenium poisoning, much remains to be done to coordinate these references and select those applicable to farm and ranch planning. Most of the work has been done outside Region 6 in South Dakota and Wyoming. In this review of the literature, the writer has selected those articles which appear to be of greatest value in an action program in Region 6, especially in soil conservation surveys.

Selenium poisoning is an important problem on large areas of range land in all of the states in this region. The following discussion will include how to recognize selenium poisoning in livestock, the counties in all four states in which seleniferous geological formations have been reported, availability of selenium in soils, primary selenium indicator plants by states, the location of specific seleniferous areas by soil analyses and analyses of the vegetation, and the application of remedial measures.

SELENIUM POISONING IN LIVESTOCK

Blind staggers is caused by the consumption of small quantities of highly seleniferous range plants which are usually associated with selenium converter plants (22). Alkali disease is caused by the consumption of vegetation, grain and forage containing up to approximately 25 p.p.m. of selenium for several days or weeks. The following material pertaining to alkali disease and its acute form, blind staggers, has been summarized from Draize and Beath (11) who performed 100 autopsies on cattle and sheep, and from Moxon and Rhian (22).

Blind Staggers	Alkali Disease
External pathology	
Early stages: slight impairment of vision; difficulty in judging distance of objects. Intermediate stages: Blindness pronounced, greater tendency to wander. Final stages: Various degrees of paralysis; abdominal pain; loss of appetite; death results from failure of respiration. In a few cases, blindness does not occur and the animals do not stagger. In some cases animals recover but the coat is rough and off-color.	Vision is not impaired and animals do not wander aimlessly. Dullness, lack of vitality, stiffness and lameness and emaciation are characteristic. Loss of long hair from switch in cattle and from mane and tail of horses and mules are accompanied or followed by lameness. Hoofs develop abnormally and become long, crooked, cracked. Coat is rough and off-color. In extreme cases death may result from starvation and thirst owing to restricted movement.
Internal patholcgy	
In blind staggers the hearts and livers rapidly become permanently injured. Petechial hemorrhages on the epicardium of the heart are common; inflammatory process invades myocardium. Liver is acutely congested and many areas of focal necrosis occurs. Cirrhosis of liver not prevalent. The liver is the first organ to become permanently injured. Atony of smooth muscles is severe especially in the gastro-intestinal tract, gall bladder and bladder. The gall bladder may be enlarged to twice its normal size. There is a stasis of food materials in the rumen and omasun especially in winter cases. There is congestion in the medulla of the kidney. Erosion of the long bones especially the tibia is found in two-thirds of the cases. High incidence of anemia in both alkali disease and blind staggers.	Lesions of alkali disease are more chronic in nature. The severest injury is noted in the heart and liver. In advanced cases the heart is invariably atrophied. The liver, often atrophied is cirrhotic. Lesions in the gastro-intestinal tract are of the same general character as observed in blind staggers. The gall bladder is rarely enlarged. The lungs are congested as in blind staggers. Kidney injury is more severe in alkali especially in sheep; the medulla in advanced cases being hemorrhagic. Erosion of the ends of the long bones are prevalent.

There is occasionally a delayed action that is particularly noticeable in those cattle and sheep that have grazed seleniferous vetches (3). Several months may elapse before an animal gives an indication of sickness. The pathology of cases of sudden crack-up points

to causes that have been slow in action but eventually became vitally destructive. The animals do not show outward signs of malnutrition.

GEOLOGICAL OCCURRENCE AND DISTRIBUTION OF SELENIUM

Three theories are offered by Lakin and Byers (18) as to the sporadic and variable concentrations of selenium: (a) The precipitation of selenium from volcanic eruptions by rain; (b) the deposition of selenium carried by rivers into salt water and its accumulation especially in fine clays and chalk deposits; (c) the leaching of selenium from igneous magma, and its accumulation and deposition through the agency of plants of the indicator types. Moxon, Olson and Searight (21) suggest that areas of Cretaceous sea bottom on which organic matter was accumulating in unusual amounts were the sites of greater chemical reduction than elsewhere and that as a result greater amounts of calcium carbonate, sulphide and selenium were deposited. They also conclude that selenium is not deposited in large amounts in sandy formations. Byers, et al (10) state that in the examination of several hundred samples of sulphide ores for selenium, no case has been found in which selenium is wholly absent. Knight and Beath (17) discuss 12 sources of selenium bearing materials: rocks and their residual soils, limonitic concretions, iron pyrites and marcasite, deep well cores, carbonaceous shales and carbon seams, buried alkali beds, impure bentonite, jarosite, lignite beds, phosphate rock, ferruginous sandstones and limey sandstones.

Formations reported to contain one or more parts per million of selenium are listed by states in Table 1. The largest number of seleniferous formations were laid down in the Cretaceous period. In this period the Pierre, Niobrara, Mancos and Greenhorn formations are widely seleniferous; however, the amount of selenium contained by the various members within these formations is variable. In New Mexico and Arizona, selenium has been found occasionally in Quarternary deposits. One or more Tertiary formations have been reported seleniferous in all four states although most Tertiary formations are not seleniferous. The Morrison formation of Jurassic period is highly seleniferous in Colorado and Utah. The Moenkopi formation of the Triassic period is seleniferous in Arizona and Utah. The oldest rocks reported to be seleniferous are of late Mississippian period or early Pennsylvanian period in Provo Canyon, Utah (5).

In Arizona, Utah, Colorado and New Mexico, shales are by far the most common seleniferous rock. Counties in the region containing toxic seleniferous areas are indicated by reference numbers to the literature cited, map, page 5. Among the most extensive areas of known seleniferous formations are the Niobrara, Pierre, and Greenhorn which cover 2000, 1100, and 300 square miles respectively in eastern Colorado (10). In northeastern New Mexico an area of 600 square miles is seleniferous and is underlain by Pierre, Niobrara and Greenhorn formations (10). Extensive areas of Mancos shales in western Colorado and eastern Utah are seleniferous (1, 6, 7, 8, 9). The Moenkopi formation is seleniferous over large areas of Arizona and southern Utah (6, 7).

Table 1. - Geological formations containing one or more parts per million of selenium by states. The numbers within the brackets refer to the literature cited.

Arizona

Quarternary
Caliche (6)

Tertiary
Alluvium (6)
Verde (5,6,7)

Triassic
Moenkopi (6,7)

Utah

Tertiary
Green River (6)

Cretaceous
Mancos (6,7,8)
Dakota (7)
? Lead concentrate (8)

Jurassic
Morrison (1,7)

Triassic
Moenkopi (6,7)

Mississippian (5)

Colorado

Tertiary
Wasatch (6,7)

Cretaceous
Lewis (6)
Mesa Verde (7)
McDermott (6)
Williams Fork (7)
Mancos (1,6,7,8,9)
Niobrara (6,7,8,10,18)
Pierre (6,7,8,10)
Carlile (10)
Greenhorn (10)
Benton (6,10)
? Bentonite (6)

Jurassic
Morrison (6,7,10)
Telluride ore (8)
Vanadium ore (8)
Sulphur (8)

Pennsylvanian
Paradox (1)

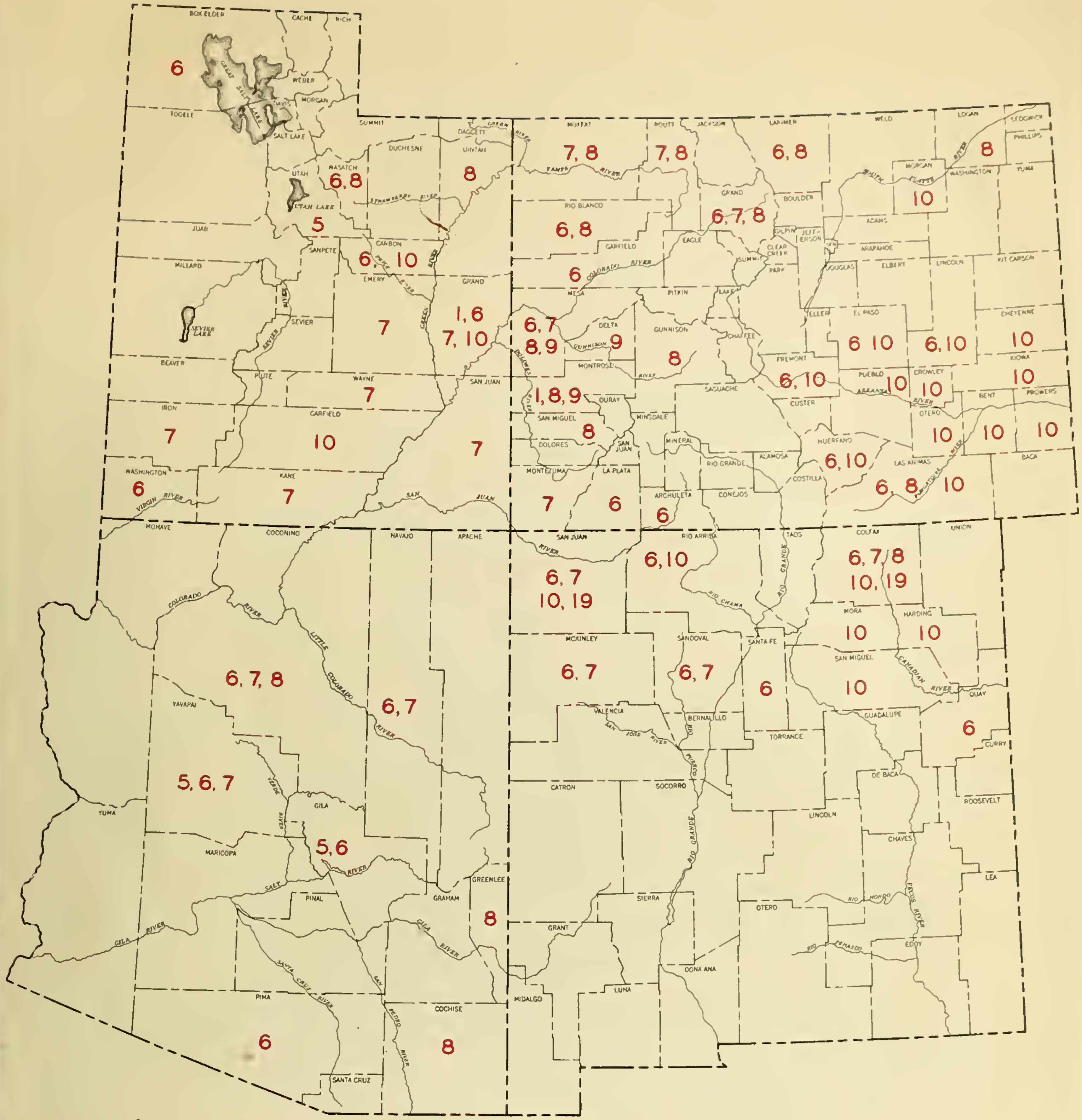
New Mexico

Quarternary
Alluvium (6)

Tertiary
Igneous (6)
Santa Fe (7)
Wasatch (7)

Cretaceous
McDermott (7)
Mesa Verde (6)
Mancos (7)
Niobrara (10,19)
Pierre (6,7,10,19)
Carlile (10)
Greenhorn (10)
? Copper concentrate (8)

Triassic
Dockum (6)



COUNTIES CONTAINING TOXIC SELENIFEROUS AREAS

SOUTHWEST REGION

ALBUQUERQUE, NEW MEXICO

50 0 50 100 150 200

Scale in Miles

April 1945

Note: Counties known to contain toxic seleniferous areas are indicated by figures on map. The figures refer to literature listed on pages 20, 21 and 22 in the bulletin on *Selenium Poisoning*, by C. H. Diebold, Region Six, Soil Conservation Service, Albuquerque, New Mexico, 1945.

SOIL CONSERVATION SERVICE, WASHINGTON, D. C. 1306 MAY 1945

SELENIUM IN SOILS

Water soluble: Selenium as calcium selenate, sodium selenate, and in the organic form from green plants is soluble in water. Water soluble selenium is readily absorbed by cereal plants, Table 2 (21). In this study of cereals 2 p.p.m. of the various forms of selenium were added to a non-seleniferous soil. However, in the case of the range plants Astragalus racemosus and Stanleya bipinnata 10 p.p.m. of selenium were added to the soil.

Table 2. - Availability of Different Forms of Selenium

Crop Grown	Selenium content (p.p.m.) of plants grown in soil containing Se in form of:						
	Na_2SeO_4	$CaSeO_4$	Na_2SeO_3	$Fe(OH)^1 SeO_3$	FeSe	Se	Organic[2]
	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Corn	269.0	lost	0.0	1.6	0.0	0.0	
Corn[3]	84.0	125.0	6.0	3.6	2.0	0.0	
Barley	92.3	197.6	10.4	10.0	0.0	0.0	180.0
Wheat	504.0	400.0	12.0			2.8	
Astragalus racemosus	2357.0	2717.0	650.0	726.0	5.0		
Stanleya bipinnata	1129.0		573.0	625.0	15.2	1.0	

1 Exact formula not known.
2 Water extract of Astragalus racemosus.
3 Second crop.

Olson and Moxon (25) state that the availability of selenium in soils appears to be dependent upon or correlated with the amount of organic selenium in the soil, Tables 3 and 4.

Table 3. - Amounts of Various Forms of Selenium in the Soils and the Relation to Selenium Content of Plants Grown on Them.

Soil No.	Humus	Total Se	Organic Se	Acid-soluble selenium	Water soluble selenium	Average Se Content of 10 crops (dry basis)
	%	p.p.m.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
1	11.3	4.8	2.1	0.33	0.05	27.368
2	11.3	5.7	1.7	0.153	0.026	12.075
3	12.7	1.7	0.42	0.199	Trace	0.15
4	12.7	3.8	1.46	0.067	< 0.026	0.65
5	10.7	6.0	1.55	0.100	< 0.026	3.205
6	4.0	4.2	0.44	0.078	< 0.026	2.552

Table 4. - Selenium Content of the Various Crops on Each Soil.
p.p.m. dry weight

Soil No.	Wheat 1A	Wheat 1B	Corn 1A	Corn 1B	Barley 1A	Barley 1C	Oats 1A	Oats 1D	Sorghum 1B	Mustard
1	35.0	28.6	16.3	9.4	28.0	13.8	23.0	29.78	4.8	85.0
2	15.0	6.5	5.6	4.0	20.0	7.1	15.0	9.25	4.3	34.0
3	0	0	0	0	0	1.2	0	0.3	1.0	0
4	0	0	0	0	3.7	0	0	0.2	0	2.6
5	5.0	0	1.1	0	8.0	0	6.0	2.45	0.5	9.0
6	3.5	0	3.4	0.6	9.0	0	4.0	2.42	0	2.6

Byers et al. (10) reported that soils containing water soluble selenium may have it present in the form of selenates and in the samples examined as calcium selenate. They also reported that the water soluble selenium compound in green plants probably contained one or more seleniferous amino acids. A part of the organic selenium may be volatilized as is indicated by the exceedingly noxious odor from decaying plants which have a high selenium content.

Beath, Eppson and Gilbert (4) found that nearly all of the selenium compounds in Xylorhizza parryi, the Astragali, the Stanleyas and species of Oonopsis could be leached by water at room temperature. They concluded that the selenium is largely in organic form since fresh aqueous extracts do not respond in any marked degree to the usual inorganic precipitants. The roots of many seleniferous range plants are high in water soluble selenium compounds. More than 50 percent of the selenium in wheat and wheat grass hay could be recovered in aqueous extracts. Based on available data it appears that roots, stubble and miscellaneous vegetation left in cropped fields are a potential and continuous source of selenium for succeeding crops.

Non-water soluble selenium: A study of Table 2 shows that the cereal crops absorbed little or no selenium when it was in the soil as either elemental selenium or pyritic selenium. Sodium selenite and ferric selenite were absorbed in small quantities by cereals (21). Byers et al. (10) and Williams et al. (27) pointed out that basic ferric selenite was very insoluble. The latter demonstrated that sodium selenite is essentially insoluble in highly ferruginous soils.

Workers in both Wyoming and South Dakota have shown that non-water soluble selenium can be absorbed by the primary selenium indicator or converter plants (17,21). For example, Astragalus racemosus and Stanleya bipinnata absorbed over 600 p.p.m. from basic ferric selenite whereas corn absorbed less than 4 p.p.m. (Table 2). Knight and Beath (17) changed non-toxic seleniferous Steele shale to a toxic condition in less than 3 years by growing from seeds some of the native seleniferous weeds such as Astragalus and Oonopsis. They also report that native grasses (mostly blue stem wheatgrass) growing close to a clump of Astragalus bisulcatus contained 70 p.p.m. of selenium. The same species some distance away contained only 11 p.p.m. of selenium.

Accumulation of Selenium

Byers (8) reported a number of selenium analyses for the Boyd series from South Dakota. He concluded that there appears to be evidence of a tendency toward accumulation of selenium at the surface and also at some point in the profile but any definite accumulation cannot be asserted. Byers et al. (10) concluded from a study of selenium data for 20 soil profiles from eastern Colorado that uniform variation with depth does not exist. The selenium content of the soil profiles studied was less than 5 p.p.m. in all but 2 cases.

The necessity of sampling the root zone for selenium is shown in Table 5 (26). Samples of the surface soil only are inadequate.

Table 5. - Relation of Soluble Selenium in Soils to Selenium in Vegetation

Soil Location Number	Total Se Content of Soils		Soluble Se Content of Soils		Se Content of A. smithii
		p.p.m.		p.p.m.	p.p.m.
6	1st foot	2.7	1st foot	0.12	18
	2nd foot	5.5	2nd foot	2.76	
	3rd foot	11.5	3rd foot	0.58	
7	1st foot	4.3	1st foot	0.43	79
	2nd foot	15.8	2nd foot	5.00	
	3rd foot	29.0	3rd foot	10.85	
8	1st foot	3.0	1st foot	1.43	8
	2nd foot	4.5	2nd foot	0.48	
	3rd foot	11.5	3rd foot	2.66	
14	1st foot	4.4	1st foot	0.91	35
	2nd foot	28.4	2nd foot	17.60	
	3rd foot	38.4	3rd foot	18.99	
21	1st foot	4.4	1st foot	0.08	2
	2nd foot	4.8	2nd foot	0.10	
	3rd foot	6.4	3rd foot	0.12	
32	1st foot	5.9	1st foot	0.11	2
	2nd foot	4.6	2nd foot	0.05	
	3rd foot	6.0	3rd foot	0.11	

For example, Agropyron smithii contained 79 p.p.m. of selenium when the soluble selenium of the surface was 0.43 p.p.m. The soluble selenium contents of the second and third foot of this soil were 5.00 and 10.85 p.p.m. The authors conclude that the subsurface soil is the more

important source of available selenium although there may be many cases where the surface soil is the source.

Estimates based on the selenium content of unweathered sections of the Interior member of the Pierre formation in South Dakota and the residual soil indicate that the loss of selenium during the soil forming process varies from 60 to 85 percent (21). In semi-arid areas a large part of the selenium is oxidized to the selenate form (26). In this form it is leached from the surface to the subsurface soil or removed by runoff waters. In irrigated areas in southeastern and western Colorado (9,10) important quantities of selenium are leached out of the soil by irrigation water. Drainage water from such areas contains appreciable quantities of selenium.

Availability of selenium

The concentration of soluble salts is not consistently related to the availability of selenium (1). For example, on a soil near Paradox, Colorado which was high in sulphates, Astragalus pattersonii contained 800 p.p.m. of selenium although the soil contained only 1 p.p.m. In contrast the same species of Astragalus on Mancos shale, which contained from 3 to 4 times as much soil selenium but less than 1 percent total salts, was found to contain appreciably less selenium than was obtained on the Paradox formation.

Hurd-Karrer (14) concluded from greenhouse studies that the tendency for a crop to absorb selenium was inversely related to its tendency to absorb sulphur. Sodium selenate was used as the source of selenium. Gile and Lakin (13) found that the toxicity of the selenite ion is not affected by the sulfate supply, provided sufficient sulfate is available for maximum growth, whereas sodium selenate toxicity was materially lessened by increasing the sulfate supply. Byers (9) concluded from extensive soil profile analyses that where the sulphur-selenium ratio is high, the selenium content of comparable plant samples is low, and conversely, when the sulphur-selenium ratio is low, the selenium content is high. This relation, however, is not consistent. It seems clear therefore that factors other than the quantity of selenium and variation of sulphur-selenium ratios affect the absorption by a given plant species.

Beath, Eppson and Gilbert (4) reported that sulphur and soluble sulphates did not inhibit the absorption of selenium by wheat on Morrison shale. The source of the selenium was organic, Astragalus bisulcatus. Franke and Painter (12) applied sulphur and gypsum to a 12 acre field (dry farming) in South Dakota which has produced seleniferous crops for the previous 24 years. Feeding experiments with white rats indicated that the sulphur had failed to reduce toxicity of corn. A study of their data shows that previous crops of both corn and wheat contained larger quantities of selenium than were found during the experiment. The authors attribute this lower rate of absorption to years of abnormally low rainfall during the experiment. In the soils studied the

ratios of sulphur to selenium were from 143 to 489 which greatly exceeds the ratio of 50 reported by Byers to prevent a dangerously high selenium content in plants.

The writer concludes from these studies that sulphur and gypsum would not pay the cost of application on western soils since the selenium is derived in part from organic sources.

Gile and Lakin (13) studying soils largely of eastern and southern origin in a greenhouse concluded that soil colloids have no effect in reducing the toxicity of sodium selenate for millet. In contrast, soil colloids have a marked effect on the availability of sodium selenite.

Both Beath (7) and Byers (9) concluded that water from wells and springs is low in selenium and seldom contains sufficient quantity of selenium to cause injury. Drainage water from certain irrigated areas in Colorado would probably produce serious poisoning but the water is essentially nonpotable (9).

FACTORS AFFECTING THE AMOUNT OF SELENIUM IN PLANTS

Species:

There is general agreement that species of plants may be grouped in relation to their tolerance of selenium (5, 6, 7, 10, 19). The first group consists of primary selenium indicator plants which are universally seleniferous in their annual cycle of growth. Beath, Gilbert and Eppson (5) list 32 species as primary selenium indicator plants which occur in one or more of 12 western states. Several additional species are listed in (6) and (7).

Since the range of these indicator plants may be limited, the writer has listed the species which occur in Arizona, Colorado, New Mexico and Utah (Table 6). A study of this table shows that certain species of Astragalus (vetch or loco) are the most numerous seleniferous plants in all four states. Beath, Gilbert and Eppson (5, 6, 7) have shown that these seleniferous Astragali belong to but 6 of the 29 groups of Astragali described by Jones (15). His classification of Astragali was based on genetic characteristics. The next most important seleniferous genus appears to be Stanleya which is a mustard. In Colorado and Utah some species of Oonopsis and Xlyorrhiza occur and they are seleniferous. Both genera are members of the Compositae and the latter is known as woody aster.

It has been long known that many of the Astragali are markedly odoriferous. It is believed that every sample of Astragalus having the characteristic odor is seleniferous (5). This odoriferous principle is not only a fairly accurate qualitative indication of selenium but also an indication as to whether the specimen is moderately or highly selenized.

Table 6. - Distribution of Primary Selenium Indicator Plants by States. Numbers After Species Refers to Literature Cited.*

Arizona

Astragalus haydenianus
A. confertiflorus (6)
A. preussi (7)
A. preussi var. latus
A. pattersonii
A. moencoppensis (7)
A. praelongus (5,6,7)
A. sabulosus (5,6)
A. beathii (7)
A. limatus
A. argillosus (7)
A. asclepiadoides

Stanleya pinnata (5,6,7)
S. albescens (7)

New Mexico

Astragalus haydenianus (6,7)
A. oocalysis (7)
A. bisulcatus (6,7,19)
A. racemosus (6,7,10,19)
A. flavus
A. confertiflorus (6)
A. pectinatus (19)
A. preussi var. latus (5)
A. pattersonii (6,7)
A. praelongus (6,7)
A. sabulosus

Stanleya pinnata (6,7,19)
S. albescens

Colorado

Astragalus haydenianus (6,7)
A. oocalysis (A. urceolatus 6)
A. bisulcatus (6,8,10)
A. racemosus (6,10)
A. osterhoutii (7)
A. flavus
A. confertiflorus (6,7)
A. pectinatus (6)
A. pattersonii (6,7)
A. praelongus
A. sabulosus
A. eastwoodae

Stanleya pinnata (6,8,10,19)
S. bipinnata
S. integrifolia (6,7)
S. albescens

Oonopsis foliosa (6,10-Aplopappus fremontii)
O. engelmanni (6)

Xlyorrhiza parryi
X. Venusta (7)
X. glabriuscula (6)

Utah

Astragalus haydenianus (6,7)
A. racemosus (10)
A. flavus
A. confertiflorus (6,7)
A. moencoppensis (7)
A. toanus (6)
A. preussi
A. preussi var. latus (5,6)
A. pattersonii (6)
A. praelongus (5,6)
A. sabulosus
A. eastwoodae (6)
A. argillosus
A. asclepiadoides (7)

Stanleya pinnata (6,7)
S. bipinnata
S. albescens

Xlyorrhiza parryi
X. venusta (6,7)

*Species listed without numbers are reported by Beath, Gilbert and Eppson (5,6,7) to be seleniferous in one or more of the western states but no analyses are given for the states in question. The botanical keys of Coulter and Nelson; Wooton and Standley; Tidestrom; Tidestrom and Kittrell; Kearney and Peebles; and Jones have been consulted to determine the range by states of these seleniferous plants for which specific data are not available.

Investigators are unanimous that converter plants may be high in selenium although the soil may contain as little as 1 p.p.m. of selenium. Byers (9) reported that Astragalus racemosus shows a range of ratios of selenium in the plant to that in the surface soil varying from 2,300 to 30. Astragalus pectinatus, narrow leaf milk vetch, shows ratios from 1,550 to 5.

The converter plants are able to take up large quantities of selenium from raw shales. Knight and Beath (17) reported that non-toxic seleniferous Steele shale was converted to toxic condition in less than 3 years by growing from seeds some of the native seleniferous weeds such as Astragalus and Oonopsis.

Plants growing close to converter or primary selenium indicator plants often contain much higher amounts of selenium. Native grasses, mostly western wheat grass, growing close to a clump of Astragalus bisulcatus contained 70 p.p.m. of selenium (17). The same species some distance away was found to contain only 11 p.p.m. of selenium. Moxon, Olson and Searight (21) reported that plants growing within a large patch of Aster multiflorus were found to have a much larger content of selenium than those taken from the nearby area where there were no asters.

The second group of plants consists of those species which are capable of absorbing selenium in toxic quantities when growing on seleniferous soils. They differ from the first group in that they are found abundantly on non-seleniferous soils and are, therefore, not indicators of selenium. Miller and Byers (19) list white wreath aster, blue aster, turpentine weed (snakeweed), sunflower, western wheat grass, wheat, rye, barley and corn as belonging to the second group. Beath, Eppson and Gilbert (5,7) list certain species of Aster, Atriplex, Grindelia, Machaeranthera, Sideranthus, Mentzelia, Pentstemon, Gutierrezia, Castilleja, etc. In this group it is difficult to distinguish between those that can absorb selenium from its naturally occurring source and those that must depend upon its being made available to them. Of special interest are the Asters since A. commutatis, A. adscendens, A. glaucus and A. ericoides are capable of absorbing toxic quantities of selenium. The seleniferous asters on some ranges occur in dense growth and markedly affect the associated palatable forages. Atriplex canescens has been found to be a dependable absorber of selenium on soils of Pierre and Niobrara origin (5). On the other hand 6 out of 8 analyses of Atriplex canescens growing on soils from the Morrison, Mancos, Niobrara and Pierre formations in Colorado contained from 0 to 6 p.p.m. of selenium (6). Moxon, Olson and Searight (21) working in South Dakota concluded that western wheat grass was apparently the most highly seleniferous of the important grasses in that state (Table 7).

The third group of plants consists of those species which absorb selenium only in small quantities when growing on seleniferous soil and which have a very limited tolerance of selenium (10). In consequence they either do not appear on seleniferous soils or have but poor growth. The most notable examples of this group are buffalo grass and grama grasses, Bouteloua gracilis and B. curtipendula (19).

Table 7. - A Comparison of the Selenium Content of Some Grasses Common to Western South Dakota

Common Name	Scientific Name	No. of analyses reported	Selenium content of plants (dry basis) p.p.m. Range	Average	Av. for species
Western wheat grass	Agropyron smithii*	75	0.0-84.0	12.11	
Western wheat grass	Agropyron smithii**	20	0.0-60.0	15.15	11.46
Western wheat grass	Agropyron smithii***	40	1.0-50.0	8.40	
Buffalo grass	Buchloe dactyloides*	5	0.0- 0.5	0.17	
Buffalo grass	Buchloe dactyloides**	3	0.0-12.0	7.33	2.65
Buffalo grass	Buchloe dactyloides***	1		1.00	
Blue grama	Bouteloua gracilis*	8	0.0- 3.6	1.40	1.40
Side oat grama	Bouteloua curtipendula*	9	0.0-32.0	4.41	
Side oat grama	Bouteloua curtipendula**	8	1.0- 8.0	2.75	3.57
Needlegrass	Stipa sp.*	3	0.0- 2.0	1.01	
Needlegrass	Stipa sp.**	22	0.5-40.0	6.70	5.61
Needlegrass	Stipa sp.***	24	1.0-10.0	5.17	
Little bluestem	Andropogon scoparius Michx.**	51	0.0- 2.0	0.75	
Little bluestem	Andropogon scoparius Michx.***	25	0.0- 6.0	2.12	1.10

* Data from this laboratory (21)
** Data from Byers (8)
***Data from Byers (9)

Stage of Growth

Moxon, Olson and Searight (21) reported that the amount of selenium on a dry weight basis in western wheat grass declined as maturity approached. The highest values occurred during the early stages of growth in May. Olson, Jornlin and Moxon (24) reported a rapid decrease in selenium content after maturity of western wheat grass owing to the combined effects of leaching, volatilization and the shedding of seeds high in selenium. The selenium content of Aster multiflorus tended to decrease throughout the period of growth on a dry weight basis except when it matured it increased slightly (21). The selenium content of Grindelia squarrosa increases in later stages of growth whereas that of sweet clover increases until the blooming stage and then it decreases. Wheat apparently decreases in selenium content at later stages of growth on a dry weight basis whereas that of oats increases. The selenium content of barley remains fairly constant.

Beath, Eppson and Gilbert (4) state that woody aster and Aster commutatis had the highest selenium content in the initial stages of growth. Astragalus pectinatus and Oonopsis condensata had the highest content during full bloom.

During the late fall Astragalus bisulcatus and related Astragali produce regrowth (4). Fresh samples of Astragalus bisulcatus analyzed:

Old stems	255 p.p.m. of selenium
Regrowth	8,000 p.p.m. of selenium
Roots	800 p.p.m. of selenium

There are appreciable differences in the selenium content of different parts of the plant. A collection made of Astragalus pectinatus, when the pods were beginning to disperse, and air dried analyzed (4):

Pods	124 p.p.m. of selenium
Leaves and stem	260 p.p.m. of selenium
Seeds	3,250 p.p.m. of selenium

Drying of Samples

The loss of selenium from certain range plants from the time collected until air dried may be as much as 66 percent (4). Usually the early succulent plants show a greater loss of selenium upon drying than the mature fibrous plants. In contrast to seleniferous range plants, selenium in wheat, oats, barley, grasses and vegetables does not volatilize upon drying.

Seleniferous Droppings

Another way in which native grasses and range forages may be influenced in their selenium intake is through the fertilizing effect of seleniferous droppings from cattle, sheep and horses (17). Feces from experimental animals and from samples taken from the ranges show that a considerable amount of selenium is excreted in this manner. The elimination of selenium through the feces has been found to continue at least two months after experimental cattle were taken from a seleniferous range and placed on non-toxic feed.

TOXIC QUANTITIES OF SELENIUM

Soils

Beath (1) states that the minimum amount of selenium which is dangerous in soils has not been determined. It may be said, however, that usually a soil containing one or more p.p.m. of available selenium is capable of supporting seleniferous grasses and grains. Byers (8) reports that any soil containing upwards of 0.5 p.p.m. of selenium is dangerous. Gile and Lakin (13) found that millet grown in one gallon pots was distinctly injured by 1.5 p.p.m. of selenium as sodium selenate. This amount might be expressed as 3 pounds per acre furrow slice.

Plants

Forced feeding trials demonstrated that 50 ounces of green, selenium free, Astragalus bisulcatus (blooming) per hundred weight of

sheep failed to seriously affect the animal (2). In contrast, 25 ounces of the same plant, of the same stage of growth per hundred weight of sheep but containing selenium, produced death within a few hours.

Knight and Beath (17) reported that there is apparently a wide variation in the amount of selenium that produces lethal effects. In areas where salt bushes and winter fat are toxic because of their seleniferous character, livestock losses are severe at times. These plants are dangerous throughout the winter months. On the other hand, horses grazed a winter range of seleniferous winter fat without exhibiting ill effects. In February a composite sample of the excreta carried 11.6 p.p.m. of selenium. Sheep have been fed naturally occurring winter fat containing 30 p.p.m. of selenium for a period of 3 months without any noticeably ill effects. The daily feedings of seleniferous winter fat constituted about 30 percent of the diet. Byers (8) states that vegetation containing 5 p.p.m. of selenium is potentially dangerous. He concludes that in general a lethal dose of selenium as it occurs in green vegetation is of the order of magnitude of 2 to 4 mg. per animal pound, for certain large animals.

Cereals and forage grown upon shales and soils of the Morrison formation in Wyoming are capable of producing alkali disease in livestock although the selenium content seldom exceeds 3 p.p.m. (17). Other elements such as molybdenum may be involved. In a carefully controlled experiment for 2 winters (23), steers were fed western wheat grass hay containing from 2.0 to 4.2 p.p.m. of selenium, and alfalfa containing 5.6 p.p.m. of selenium. The only lot of steers which gained during the winter months was given arsenic salt. During the rest of the year the animals were grazed on a seleniferous wheat grass range. In one pasture averaging 4 p.p.m. of selenium in wheat grass, all of the steers developed cracked hoofs which is typical of alkali disease. Knight and Beath (17) state that cattle can tolerate for a period of at least six months toxic wheat grass hay carrying an average selenium content of 15 p.p.m. One may conclude from a review of the literature that numerous factors affect the toxicity of selenium.

REMEDIAL MEASURES

Determination of Seleniferous Areas

Through the use of geologic maps, plant indicators and local history, the general location of many seleniferous areas is roughly known. Within these areas there may be sizeable areas which are relatively free of selenium.

The exact location of seleniferous soils capable of producing toxic vegetation could be determined by taking soil samples for selenium analyses while making detailed soil conservation surveys supplemented by the odor and selenium analyses of the vegetation.

Byers et al. (10) showed that in southeastern Colorado, the vegetation was highly seleniferous on the Niobrara formation whereas there was very little selenium in vegetation in an adjacent area of Fort Union formation. Moxon, Olson and Searight (21) state that instances were encountered during field work where fencing off two or three acres on a farm would eliminate the sources of considerable livestock trouble. In other cases, it would of course, require the withdrawal of larger areas from the production of livestock feed. Probably the most effective control measure for application in the most toxic areas would be detailed mapping of seleniferous formations and seleniferous soils on individual farms and ranches. Beath (1) is of the opinion that there is no substitute for an analysis of the plants themselves.

It should be pointed out that except for the occurrence of indicator plants and in some instances a noxious odor, seleniferous areas cannot be determined in the field. Since it is important to determine as little as 0.5 p.p.m. of soluble selenium in the soil, tests for selenium require good laboratory apparatus and technique. A review of the methods for determining selenium has been presented by Klein (16). None of the methods appear to be of promise for field determinations. Therefore, in order to prove that a soil is not a potential source of selenium, laboratory analyses for both selenium and water soluble selenium should be made for the effective depth of rooting.

Time of Grazing

Since grasses and other plants often lose appreciable quantities of selenium upon drying, the deferred use of such areas for late fall and winter grazing deserves consideration. Such pastures might coincide with moderately seleniferous areas.

Eradication

The eradication of selenium converter plants deserves careful consideration. In some cases it may be practical by pulling up the plants and burning. In more extensive areas, range management may be the key to the problem.

Reduction of Stocking

Although reduction in stocking is sometimes helpful in reducing selenium injury, understocking as a single remedial measure appears questionable in the study made by Moxon, Rhian, Anderson and Olson (23). Steers in the one-half normal grazing capacity pasture gained only nine pounds more per month for a period of 3 summers than those in the normal grazing capacity pasture. Steers in both pastures developed symptoms of alkali disease. It is apparent that reduction in grazing capacity is not a complete answer. Beath, Eppson and Gilbert (3) report that in Wyoming the critical death loss period develops at the time

cattle and sheep are being trailed and concentrated from summer ranges to winter headquarters. It has been observed repeatedly that some cattle will seek out the two grooved milk vetch (Astragalus bisulcatus) in preference to cut-over native meadows and alfalfa during the first few days of the adjustment period. This particular grazing preference for a limited time indicates a depravity for some particular element held by the vetch.

Arsenic

Moxon, Rhian, Anderson and Olson (23) carried out an investigation concerning the growth of steers on seleniferous range. A ranch in Lyman County, South Dakota was selected which was known to produce numerous cases of alkali disease. In 1939, 20 yearling steers were purchased locally from nearby seleniferous ranches; 20 yearling steers were purchased from a non-seleniferous area in the eastern part of the state. Five steers from each source were placed in separate pastures (Table 8).

Table 8. - Average gain of steers during summer by lots.

Lot	Acres per head	Average initial weight	1939 6/21-9/21	1940 5/21-9/21	1941 5/21-9/21
			Average gain per lot in pounds		
I	10	477	96	190	181
II	30	476	109	206	233
III	20	475	97	182	180
IV	20 and arsenic salt	476	109	187	226

Lot IV received salt containing arsenic. From June to September 1939, salt containing 5 p.p.m. of arsenic was provided, from September 1939 to July 1940 the salt contained 10 p.p.m. of arsenic and after that 25 p.p.m. of arsenic. (In preparing the salt mixture, 1.83 grams of sodium arsenite and approximately 23 grams of salt were ground in a mortar to secure intimate mixing. This salt and arsenic mixture and 100 pounds of loose stock salt were then mixed thoroughly in a small concrete mixer.)

In September 1940, two steers from each lot were sold. They were replaced with heifers to begin a study of the effects of selenium on reproduction. The remaining steers were left in the original lots until spring. In July 1941, 10 more heifers were put in the lots, five in lot III and five in lot IV. Two steers from lot II and one from lot IV were put in lot I and one from lot III and two from lot IV were put in lot III.

A study of Table 8 shows that during the summer season the steers in the undergrazed pasture II and normal pasture with arsenic salt made the best gains. On the other hand, based on the weight of the steers which were sold in September 1941, lot IV made the best gains (Table 9).

Table 9. - Average weight and sales prices of steers, September 1941.

Lot	Weight	$ per cwt.	Total value	Average selenium content[b]	
I	1043.9	8.65	90.53	4.07	6.15
II	1020.5	8.70	88.69	12.84	5.11
III	985.0[a]	8.65	85.42	13.09	5.38
IV	1165.0	8.95	104.16	7.92	5.89

a. One steer had a lump jaw and weighed 185 pounds less than average.
b. Average selenium content p.p.m. of Agropyron smithii for 1940 and 1941 in respective columns.

A further study of the data shows that the steers from lot IV maintained their weight during the winter of 1940-41 much better than those from other lots. During the winters the steers were in a pasture near the barn and were fed 20 tons of western wheat grass hay containing from 2.0 to 4.2 p.p.m. of selenium and 10 tons of alfalfa containing 5.6 p.p.m. of selenium.

Analyses of the selenium content of the organs of the steers were made at the end of the period when the steers were sold in 1940. The average selenium content of the meat was .9 p.p.m. whereas the selenium content of the meat of the steers sold in 1941, averaged 3 p.p.m. Similar increases in selenium content were noted in the kidney, liver, spleen and blood. However, lot IV which received the arsenic salt had a much lower selenium content in the blood, particularly those which were sold in September 1941. The selenium content of the other organs and the meat did not appear to be significantly affected by the addition of arsenic.

Careful observations of the symptoms of selenium poisoning were made and recorded at several different times during the course of the experiment. The symptoms appeared each summer or fall about the time the grass began to dry up as a result of hot dry winds. The first noticeable symptom was lameness or stiffness of the forelegs. This was followed in a few weeks by cracking of the hoofs at the growing point. New growth of hoofs started and eventually the old hoof became detached. By the end of the winter most of the symptoms had disappeared and by spring the steers were thin but in good condition otherwise. A record of the incidence of symptoms indicated that during 1939 and as late as September 1, 1940 certain steers in all four lots had cracked hoofs. Thereafter in 1940 and in 1941 no animals were found with cracked hoofs in lot IV although one or more steers had cracked hoofs in the other lots. Therefore the addition of arsenic to the stock salt prevented the occurrence of symptoms associated with alkali disease. Moxon and Olson stated in the 1940 annual report of the South Dakota Agricultural Experiment Station that apparently naturally occurring arsenic is of little benefit in counteracting selenium poisoning.

Linseed Meal

From feeding rations of high, normal and low protein content it

was concluded by South Dakota workers (22) that selenium poisoning was less severe on the ration with a high protein content with certain animals. In experiments with rats and dogs, linseed meal gave good protection from a ration containing 10 p.p.m. of selenium.

Later, Moxon (20), made a progress report pertaining to feeding linseed meal to beef cattle on a seleniferous ranch in South Dakota. Twenty head of young beef cows were divided into two lots. Lot I received one pound of linseed meal per head daily the year around in addition to summer and winter range and supplemental feeding of hay during the winter. Lot II served as a check lot and had the same treatment as Lot I but did not receive linseed meal. For the period January 1941 to September 1943 the linseed meal lot gained slightly more than the check lot but the difference is not statistically significant. Moxon states that three years results will be desirable before definite conclusions are made regarding the value of linseed meal for cattle in seleniferous areas.

Range Reseeding

A soil analysis of total and water soluble selenium should be made in areas proposed for range reseeding that are known to be underlain by seleniferous geological formations (Table 1). If more than 1 p.p.m. of water soluble selenium occurs within the effective depth of rooting, the use of species such as Agropyron smithii and Atriplex canescens is questionable. The former was found to be relatively more seleniferous than other important grasses in South Dakota. The latter has caused severe losses of livestock although there are certain conditions when it does not. Galleta grass has been observed to cause poisoning by selenium in certain local areas in the region.

Temporary Pastures

The use of small grains for temporary pasture on seleniferous soils may be dangerous. Wheat, barley and oats can accumulate selenium in toxic quantities; permanent injury to internal organs of livestock can occur in a few weeks due to selenium.

Stock Water Facilities

Stock water ponds or tanks should be located so as to avoid the areas producing appreciable quantities of toxic seleniferous vegetation. Although data are lacking, it would appear logical that flash flows from areas containing primary selenium indicator plants would contain appreciable quantities of selenium from these plants and organic residues. The location of wells and other stock water facilities so as to avoid overgrazing seleniferous areas deserves consideration.

Irrigation

Large quantities of selenium may be leached out of soils by irrigation water. Byers et al. (10) state that irrigation provides a remedy for seleniferous soils wherever it can be practiced if adequate

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underdrainage is provided. On the other hand, the use of irrigation water high in selenium has produced seleniferous crops in the Irapuato area, Mexico (27). In this area irrigation as practiced is not a remedial measure partly because the section is semi-humid and therefore does not require continuous irrigation and partly because of the presence of selenium in the water.

Sulphur

As previously pointed out, the use of either sulphur or gypsum is not practical on naturally seleniferous soils.

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